

RESEARCH PAPER

# Trend and Change-Point Detection of Rainfall and Temperature Extremes in the Northwestern State of Nigeria

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## Abstract

Insights into temperature and rainfall extremes are essential for managing climate-related risks. This study examines variability and behavior of temperature and rainfall extremes in Kano, a semi-arid city in northwestern Nigeria. Daily observations of maximum temperature and rainfall were analyzed. The focus was on seasonal distribution, event frequency, and possible shifts in extreme conditions. Extreme events were defined using the 95th percentile threshold. This resulted in thresholds of 41.00 °C for maximum temperature and 16.30 mm for rainfall. Trend detection was carried out using the Mann–Kendall test and Sen's slope estimator. Pettitt's test was applied to identify change points in event frequency. Seasonal and annual frequencies were also evaluated. Extreme heat events were strongly concentrated in spring, accounting for 98.28% of all heat extremes. Most extreme rainfall events occurred in summer, representing 78.01% of the total. No statistically significant trends were detected for either variable. A slight decline was observed in heat extremes. Change-point analysis indicated a shift in heat extremes after 2016 and in rainfall events around 2020. The findings support the need for localized assessments to guide planning in agriculture and water management in semi-arid regions.

**Keywords:** Climate variability; Temperature extremes; Rainfall extremes; Trend analysis; Change-point detection.

## 1. Introduction

Climatic variability differs across regions and directly affects key sectors such as agriculture, water resources, and public health. It has risen since the 1950s and notably since the last decade due to increasing atmospheric concentration of human-emitted greenhouse gases [1], [2]. One of the major indications of such change is rising land and sea-level temperatures, and they have increased by approximately 0.7°C globally since last century, with land surfaces warming at a higher rate than oceans [3]. Such warming has far-reaching impacts on climate and weather-related extreme events. The warming is also likely to cause frequent heatwaves and altered timing of rainfall, particularly where such stress is already sensitive to environmental stress. Climate change and global warming complicate the identification of the onset, cessation, duration, and shifts in seasonal rainfall patterns [4], [5]. In West African Sahel, both maximum and minimum temperatures increased in the Sudanian, Sahelian, and Sahelo-Saharan ecological zones, with temperature at nighttime increasing at a higher rate [6], [7], [8].

Analysis of climatic variables offers important insight into environmental and socio-economic impacts in arid and semi-arid regions [9], [10]. Understanding temperature and rainfall extremes is needed to assess climate-related hazards to food production and water supplies [11], [12]. The extremes tend to cause critical events like droughts, floods, and heatwaves, and these immediately impact communities and ecosystems. Four categories of climate extremes exist: temperature extremes, precipitation extremes, river floods, and tropical cyclones [13]. Heatwaves can disrupt ecosystems and water availability, while intense rainfall can increase flood risk when drainage capacity is exceeded. Tropical cyclones, regionally termed hurricanes or typhoons, tend to produce intense rain that further exacerbates flood hazards in at-risk areas.

Monitoring climate variables over time helps clarify the pace and direction of environmental change. Trend analysis plays a key role in identifying early signals in temperature and rainfall extremes. However, climate time series show strong variability and irregular behavior, which complicates trend detection [14]. This has led to the development of a wide range of analytical approaches aimed at improving robustness and reliability [15]. Methods applied to rainfall and temperature extremes include non-parametric tests such as the Mann-Kendall (MK) and Spearman's Rho (SR), parametric regression techniques, percentile-based indices, extreme value analysis, and time-frequency tools such as wavelet analysis. While these approaches are widely used, many focus primarily on monotonic trends and may not capture abrupt shifts or non-linear behavior in climatic records [16]. This limitation becomes more pronounced for regions with strong local variability.

Several methods also rely on assumptions of normality and independence, which are violated in observed climate data. To address some of these limitations, innovative trend analysis (ITA) was introduced [17]. ITA allows visual identification of trend behavior and has been applied across different climatic regions [18], [19]. Its graphical structure makes it useful for detecting subtle or masked changes that may not be evident using classical tests [20]. Despite these advances, many existing studies remain limited in scope. Trend assessments are based on a single method, focus on long-term means rather than extremes, or examine large spatial scales while overlooking local conditions [20], [21]. Change-point detection is also frequently excluded, even though abrupt shifts are common in climate extremes.

In northern Nigeria, climate-related stresses have increased in recent decades. Rising temperatures and prolonged heat events have affected agriculture and public health. Rainfall remains highly seasonal and concentrated in short periods, increasing exposure to both drought and flood. These conditions are particularly critical in semi-arid areas where water and agricultural systems are already vulnerable. Rapid urban growth and limited adaptation capacity further amplify climate impacts [22], [23]. Despite these challenges, few studies have examined recent temperature and rainfall extremes in Kano using both trend and change-point approaches. There are limited insights into the seasonal variability of extreme events and whether recent shifts have occurred on the local scale. To address this gap, the present study applies the Mann-Kendall test, Sen's slope estimator, and Pettitt's test to daily maximum temperature and rainfall extremes. The analysis focuses on recent variability, seasonal behavior, and potential change points. The results aim to support climate-sensitive planning related to agriculture and water management in Kano.

**Table 1:** Comparative summary of climatic trends and change-point studies across regions.

Authors	Region	Study period	Variable(s) analyzed	Trend direction (Heat)	Trend direction (Rainfall)	Change points detected	Key findings summary
[24]	South Korea	1974–2023	Tmax, Tmin, Mean Temp, Rainfall	Increasing (Monotonic and Non-monotonic)	Mixed (Mostly increasing)	Yes (by region/season)	Significant warming in all regions, especially in spring; rainfall trends more variable with increases in summer/autumn.
[25]	Awash River Basin, Ethiopia	1978–2098 (Projection)	Tmax, Tmin, Rainfall	Increasing (SSP2–4.5 and SSP5–8.5)	Increasing (up to mid-century, then declining)	Yes (2036–2043)	Projected rise in temperature across basin zones; rainfall increases until mid-century, then declines; significant spatial variability.
[26]	Botswana	1961–2020	Rainfall	N/A	Mixed: No significant trend (MK); ↑ / ↓ (ITA)	Yes (via ITA)	Traditional MK test showed no significant trends; ITA revealed more pronounced rainfall changes, especially in eastern and northern regions. Rainfall variability high with PCI > 20 for most stations.
[27]	Nouhao Subbasin, Burkina Faso	2021–2050 (Projections)	Tmax, Tmin, Mean Temp (Tmean), Temperature Indices	Increasing (warm days/nights), Decreasing (cold days/nights)	N/A	Yes (projected shifts by 2030s and 2040s)	Significant rise in warm extreme temperature indices under RCP 4.5 and RCP 8.5; projected decrease in cold extremes; increasing risks for agriculture, health, and water systems.
[28]	Center and Southeast of Iran	1985–2018	Heat wave number (HWN), duration (HWD), frequency (HWF), mean (HWM), amplitude (HWA) based on EHF	All five heatwave characteristics showed increasing trends; particularly strong post-2001; rising SST, air temp, geopotential height and specific humidity noted as drivers	N/A	Yes (post-2001 increase)	Heatwaves have intensified in number, duration, and intensity. Atmospheric drivers include increased SST, specific humidity, air temp, and geopotential height; zonal wind decreased.
[29]	Six regions, Thailand	2001–2020	Temperature, Precipitation, RH, Humidex	Increasing in all regions (MK and ITA); not all significant	Mixed trends; some decreasing (N and NE), some increasing (S, C, E)	Yes (via ITA pattern change)	Overall upward trend in temperature and humidex; mixed rainfall trends; graphical ITA and MK methods used jointly to identify trends and shifts.
[30]	South Asian Capitals (8 cities)	1982–2020	Rainfall intensity, depth, frequency, seasonal/annual rainfall trends	N/A	Mostly increasing trends (MKT and ITA); some monthly and winter decreases in Delhi, Kathmandu, and Male; rising trends in annual rainfall for most cities	Yes (monthly and seasonal variation)	Rainfall trends are rising in most South Asian capitals, aiding groundwater recharge. Declining or stagnant trends in Delhi and Male pose risks; ITA and MKT results align.

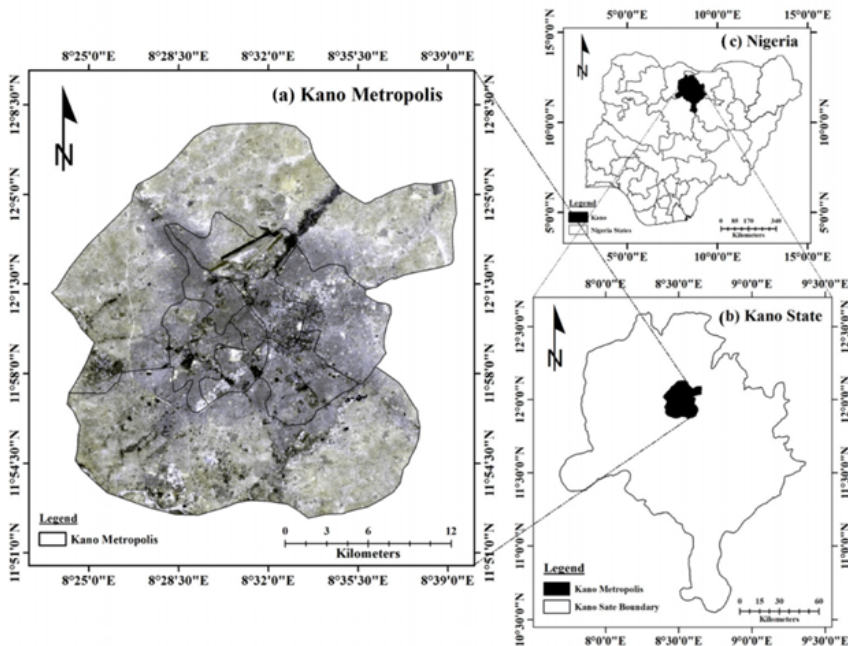
[31]	India (urban and peri-urban stations)	1971–2021	Humid heatwave intensity/duration, sub-daily rainfall (EP), CMHP frequency	Weak to moderate increase in peak wet-bulb temperature (Tw, Twmax) in 30% of stations	Mixed: decrease in EP in 40% of sites after humid heatwaves; increase in coastal zones	Yes (regional CMHP hotspot shifts and trends)	Compound humid heat–extreme rainfall events (CMHP) are increasing, especially in monsoon/post-monsoon; stronger EPs follow high-intensity but not long-duration heatwaves.
[32]	Wadi Sebou Basin, Morocco	1961–2018	Rainfall	N/A	Decreasing (Annual and Seasonal)	Yes (via ITA method)	ITA detected significant negative trends in rainfall across most stations, especially during winter and spring; MK detected fewer trends; ITA proved more sensitive and revealed hidden shifts.
[33]	Sirajganj, Bangladesh	1965–2021	Monthly and annual rainfall volume, dry/rainy days	N/A	Predominantly decreasing trends in rainfall volume; especially in May–September and annual rainfall	Yes (e.g., 2001, 2003, 2008, 2010 at multiple stations)	Significant reductions in rainfall found during the rainy season; increasing dry days and decreasing rainy days over time; shifts in trend direction detected post-2000.
[34]	West China	1961–2020	Autumn Rainfall	N/A	Reversal in late 1990s (↓ before, ↑ after)	Yes (1998)	WCAR showed a declining trend before 1998 and increasing trend after; changes linked to SST anomalies in subtropical South Pacific and atmospheric circulation shifts including EAJ displacement.
[35]	Middle East and North Africa (MENA)	1871–2012	Widespread heat days (WHDs), 2-m temperature	Strong increasing trends in WHDs since 2000; significant rise from August to February; most WHDs occurred post-2000	N/A	Yes (temporal split: pre-1941 vs. post-1942)	WHDs expanded significantly in the second period (1942–2012); most widespread WHDs in cold months post-2000; spatially inconsistent trends with significant rise linked to global warming.
[36]	East North-east Brazil (Alagoas)	1960–2016	Rainfall (Monthly, Seasonal, Annual)	N/A	Decrease in rainy season, increase in dry season	Yes (1980s–1990s)	Mixed trends: increased rainfall during dry months and decline in rainy months; breakpoints linked to ENSO and PDO variability; regional planning implications.

Table 1 provides a comparison of findings from similar studies conducted across Africa, Asia, and South America. Several of these studies report increasing trends in temperature extremes and mixed or declining rainfall trends. Others, particularly those using climate projections under future emission scenarios, indicate that heat-related extremes are expected to increase in both intensity and frequency in the coming decades. In contrast, the current study did not detect strong trends, but the detection of change points suggests that internal climate variability remains an essential factor. The absence of significant trends could also be due to localized influences, including land-use changes, urban growth, or limitations in climate data coverage. Nonetheless, the results contribute to the understanding of how extremes manifest at a local scale and provide a foundation for future research based on longer datasets.

## 2. Materials and Methods

### 2.1 Description of the study area

Kano City lies near the geographic centre of Kano State in Northern Nigeria, as shown in Figure 1. It extends between latitudes  $11^{\circ}52'N$ - $12^{\circ}07'N$  and longitudes  $8^{\circ}24'E$ - $8^{\circ}38'E$ . Both natural and human factors, including geology, land use, and climate, shape the hydrogeology of Kano City. The factors influence crucial processes like groundwater recharge, infiltration, surface flow, and evaporation [37]. As of 2024, Kano has approximately 16 million inhabitants, with an average annual growth rate of 3.2%. Its large population and intense economic activity make Kano City a leading hub for trade and agriculture in Northern Nigeria.

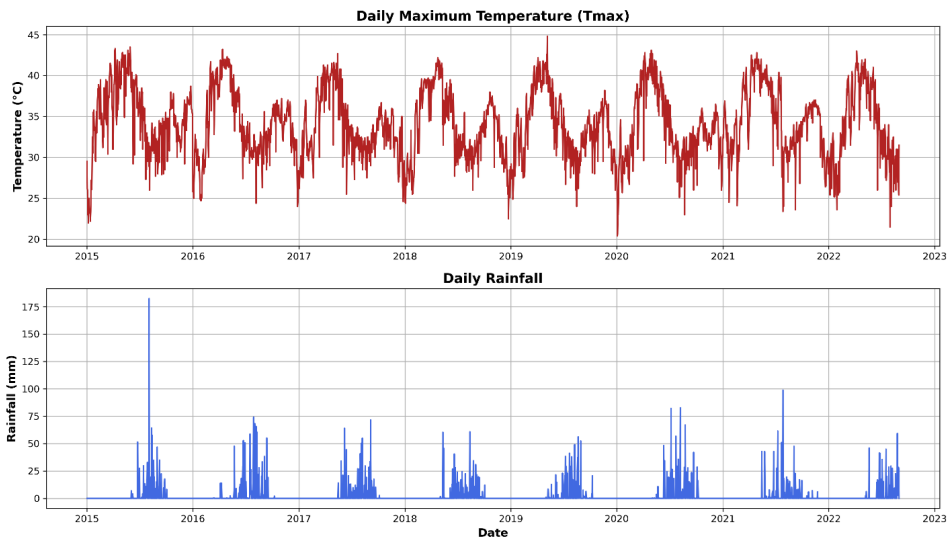


**Figure 1:** Location of the study area showing (a) Kano metropolis, (b) Kano State, and (c) Nigeria [38].

### 2.2 Data collection and processing

This study used daily climatic data obtained from the Nigerian Meteorological Agency (NiMet) (<https://nimet.gov.ng/>). The dataset covers the period from January 1, 2015, to December 31, 2022,

and includes observations from a single weather station in Kano. Two key climatic variables were analyzed: daily maximum temperature (Tmax) and daily rainfall. These variables were selected because of their relevance to the study of extreme events and their significant impact on agriculture, water availability, and local climate behavior. Before analysis, the data were checked for missing values and obvious outliers. Days with missing records were either removed or marked appropriately to avoid bias in the results. Dates were converted into standard datetime format, and the data were organized by year, month, and season to support annual and seasonal comparisons. The cleaned dataset was then used to generate time series for Tmax and rainfall. Figure 2 shows the daily time series of Tmax and rainfall for the whole eight-year period. The temperature plot reveals intense seasonal cycles, with Tmax values generally rising during the early part of the year and falling during the rainy season. Peaks typically occur between March and May, consistent with Kano's characteristic pre-rainy-season heat regime.



**Figure 2:** Daily time series of maximum temperature and rainfall.

## 2.3 Analytical methods

### 2.3.1 Extreme event definition (95th percentile threshold)

Each of these variables was considered extreme when it exceeded the 95th percentile. The method guarantees that extremes correspond to the local skewness of the distribution, and its use ensures temporal consistency across periods. The analysis was conducted using Tmax and daily rainfall data. The threshold was calculated from the entire time series, and its use enabled extreme application as a fixed level. The application of percentile-based thresholds is routine in climate research, especially when analyzing extreme event frequency and intensity [39]. The use of percentile-based thresholds in observational data analysis is preferable because it does not assume any specific distribution of temperature or rainfall.

### 2.3.2 Trend detection

The Mann–Kendall (MK) trend test was employed to identify long-term trends in extreme event frequency. It is a nonparametric test assessing whether a time series exhibits an upward or downward

monotonic trend. This is extensively used in analyzing climate because it does not necessitate normally distributed data [40], [41]. The test statistic  $S$  is defined as:

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^n \text{sgn}(x_j - x_i) \quad (1)$$

Where the sign function is:

$$\text{sgn}(x_j - x_i) = \begin{cases} +1, & \text{if } x_j - x_i > 0 \\ 0, & \text{if } x_j - x_i = 0 \\ -1, & \text{if } x_j - x_i < 0 \end{cases} \quad (2)$$

The validity of the trend is assessed based on the calculated p-value. The size of any trend is estimated using Sen's slope estimator. This algorithm estimates the median slope between each pair of values and yields a robust estimate of the rate of change. A positive slope and a decreasing trend by a negative slope give an increasing trend. The combination of MK and Sen's slope offers an effective means of examining both the presence and magnitude of any trends in extreme event frequency.

### 2.3.3 Change-point detection

Change-point analysis was conducted to detect abrupt changes in extreme-event frequency over the study period. The Pettitt's test was employed to achieve this. The Pettitt test is a nonparametric test used to identify a single change point in a time series without assuming any known distribution [42]. The test determines the probable year in which the series of data experiences a statistically significant change in median. This is particularly useful in climate studies where sudden changes can be due to large-scale climate anomalies or regional environmental shifts. In conjunction with statistical results, time series were plotted with overlaid breakpoints to facilitate interpretation. The combination of statistical detection and graphical representation provides increased confidence in results [43].

### 2.3.4 Temporal frequency analysis

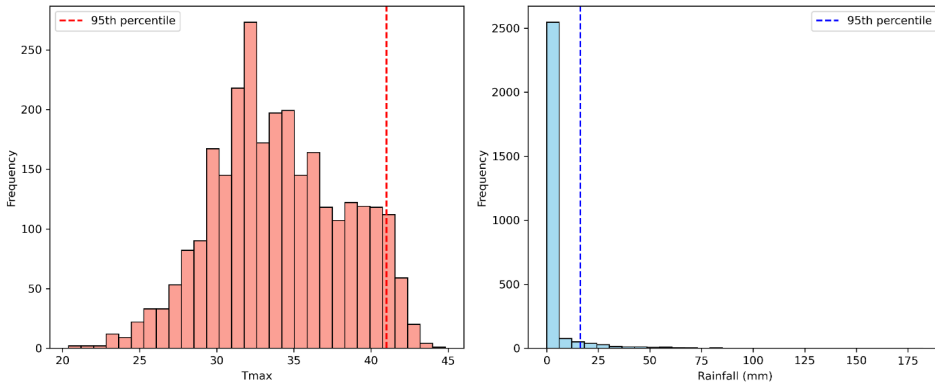
The frequency of extreme events was assessed at annual and at seasonal scales. Annual values were determined by tabulating the number of days annually that extreme rainfall and extreme heat occurred. Seasonal values were calculated by aggregating months into four standard seasons: winter (December–February), spring (March–May), summer (June–August), and autumn (September–November). This enabled seasonality of extreme events to be identified. The resulting statistics were displayed as bar plots to highlight temporal trends in frequency. This method offers an easy means of examining interannual variability and ascertaining how extremes are distributed by years and seasons [44], [45]. This determination is vital for supporting warning systems and for agricultural scheduling and planning of water resources.

## 3. Result and discussion

### 3.1 Distribution and frequency of extreme events

Extreme events in this research were identified using the 95th-percentile threshold, whereby any value at or above the 95th percentile was classified as an extreme event. On this basis, the  $T_{\max}$  extreme threshold was set at  $41.00^\circ\text{C}$  and the extreme rainfall at 16.30 mm. The thresholds provide a uniform statistical framework for distinguishing between normal and extreme climatic values in the area. To further describe the distribution of these events, a histogram of  $T_{\max}$  and rainfall was prepared (Figure 3). The histogram of  $T_{\max}$  indicates a moderately skewed distribution with visible concentration between  $30$  and  $40^\circ\text{C}$  with a steep decline beyond the 95th percentile. This suggests that extremely high temperature values are infrequent, but when they occur, they have

significant impacts. On the other hand, the rainfall histogram exhibits a pronounced right skew. Most daily rainfall events were recorded below 10 mm, with only a small fraction exceeding the extreme threshold of 16.30 mm. This skewness indicates that high-intensity rainfall events are rare and concentrated within specific months, consistent with the short but intense rainy season observed in Kano. From a climate risk perspective, the detection and understanding of extreme events are vital for informing early warning systems, land-use planning, and sustainable agricultural calendars [46]. Their impact extends beyond environmental factors to influence socioeconomic activities, particularly in regions where livelihoods depend directly on weather-sensitive sectors.



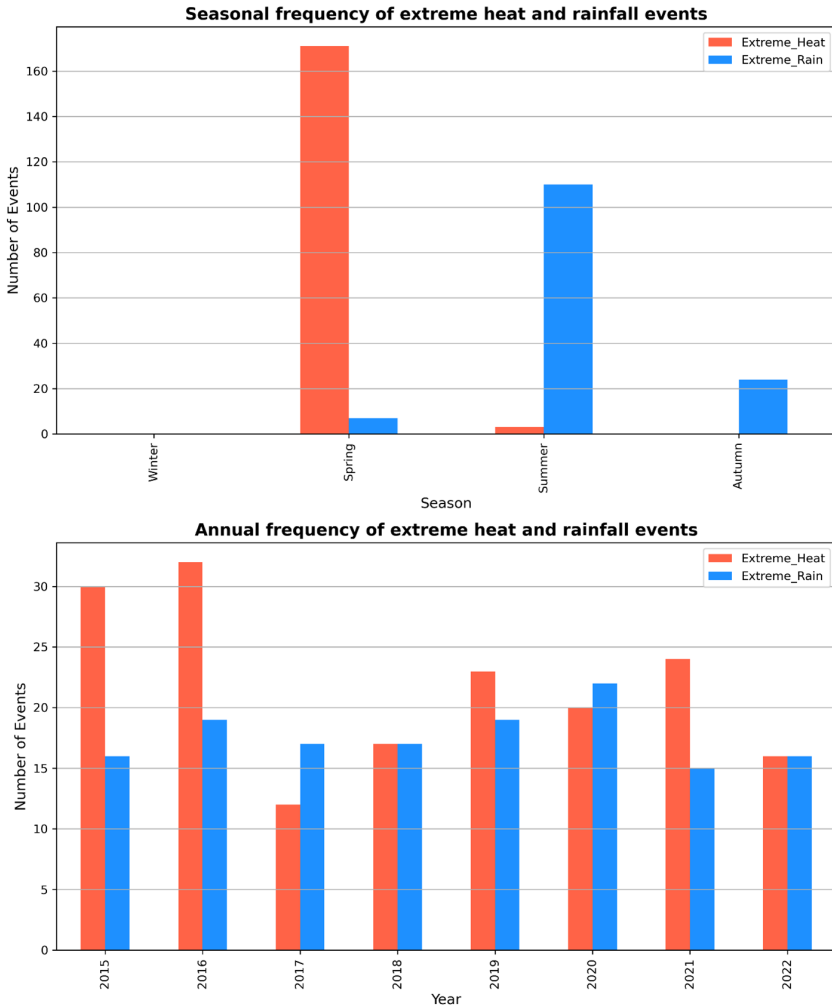
**Figure 3:** Histogram of Tmax and rainfall with 95th percentile thresholds for extreme events.

Figure 4 presents the seasonal and annual frequency of extreme heat and rainfall events. The seasonal distribution indicates that extreme heat events occurred almost entirely during the spring months, accounting for over 98% of all heat extremes during the study period. This concentration mirrors the typical pre-rain-season heat buildup in northern Nigeria, where high solar radiation and minimal cloud cover result in sharply rising temperatures. Extreme rainfall events were most common in summer, accounting for more than 78% of total events, with a minor contribution in autumn and minimal activity in spring and winter. This is consistent with the region's climatic regime, in which rainfall is primarily limited to the summer months due to the influence of the West African monsoon system [47]. Annual frequency plots (Figure 4) indicate that extreme heat events peaked in 2015 and 2016, declined in 2017, and subsequently oscillated in subsequent years. This is representative of interannual variation in temperature regimes driven by large-scale climate drivers. The annual distribution of extreme rainfall is balanced, with the maximum in 2020 and generally uniform across the years 2015–2019. One of the lower-frequency years was 2022 for both types of extremes. The above patterns reveal how short-term climate variability, such as seasonal timing and rainfall intensity, can significantly influence the frequency of extremes. From the perspectives of agriculture and water resource management, the seasonality of extreme-concentration patterns is of paramount importance.

### 3.2 Trend analysis results

Trend analysis of extreme climatic events is crucial to identify long-term weather behavior changes. The MK trend test and Sen's slope estimator were used in this study to analyze extreme heat and rainfall events between the years 2015 and 2022. The test of extreme heat events yielded the p-value of 0.53619, well above the standard p-value of 0.05. This shows that the observed changes between years are far from significant. The Sen's slope is calculated at  $-1.675$ , indicating a slight declining trend and implying that frequency of extreme heat events could have fallen between years. However,

since this is not significant, it can be dismissed as any kind of consistent or reliable change in behavior. The existence of yearly fluctuation is recognized, yet it indicates no lasting tendency in either positive or negative direction.

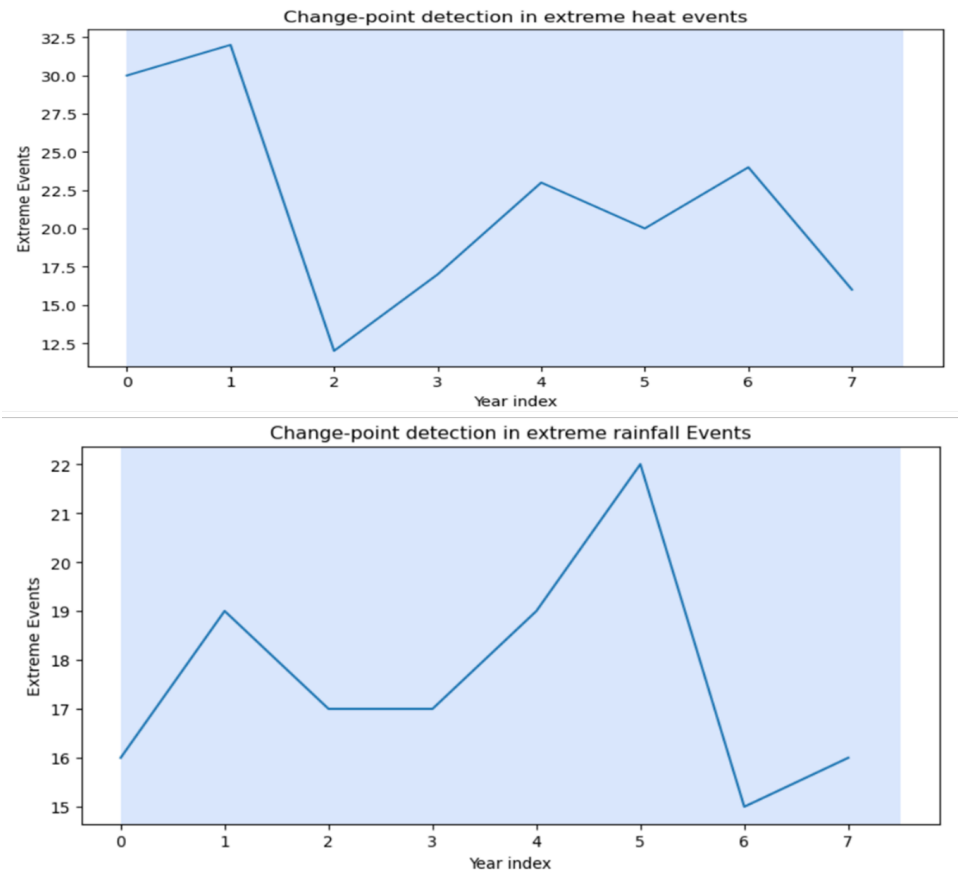


**Figure 4:** Seasonal frequency of extreme heat and rainfall events for monthly and annual periods.

Similarly, extreme rainfall event analysis revealed no statistically significant trend. The p-value of the Mann–Kendall test was 1.000, and Sen’s slope was 0.000, reflecting no directional change at all. This indicates that there was no change in the frequency of extreme rainfall events over the eight years of the study. The lack of trends in both variables indicates that, although there were some annual fluctuations, there is no evidence of increasing or decreasing extremes in Kano during this period. This result is in line with tropical and semi-arid regions’ typical short-term climate variability, where changes tend to be limited to marginal ranges and may not show broader climatic change to date [48], [49]. From a planning perspective, this underscores the need to exercise caution when monitoring changes over long horizons and to account for the timing, duration, and intensity of events when assessing climate-related risk.

### 3.3 Change-point detection

Change-point analysis is used to identify abrupt shifts in a time series that may not be captured by trend analysis. A change point refers to the time at which a significant alteration in the behavior of a variable occurs. Such changes may result from climatic variability, environmental feedback, or external forcing mechanisms. Figure 5 illustrates outcomes of change-point detection of the annual frequency of extreme heat and extreme rainfall events between 2015 and 2022. For extreme heat events, there was a change point after the year 2016, followed by a significant decline in frequency since 2017. This can be attributed to fluctuations in atmospheric circulation modes, seasonality, or energy-balance processes that influence heat accumulation in Kano. For extreme rainfall events, there was a change point around 2020, indicating a decline in their frequency. This implies that the rainfall pattern in Kano may have undergone an eventual, longer-term structural change beginning that year.



**Figure 5:** Change-point detection in extreme heat and rainfall events.

The detection of these changes is significant, as they may indicate shifts in climatic risks. Declines in extreme heat events since 2016 would be desirable in the short term by decreasing heat stress in plants, animals, and urban residents. Such changes, however, do not necessarily imply long-term stability and may reverse as subsequent climatic trends unfold. Declines in extreme rainfall events since 2020 would be signifying less intensity of seasonal peaks in rainfall, decreasing surface runoff, water storage, and recharge of groundwater. For agriculture, these changes are critical. A delayed or weakened onset of rainfall or reduced number of intense rainfall days can negatively

impact sowing schedules and crop growth. Similarly, a decrease in extreme heat events may reduce evapotranspiration losses but also alter the heat accumulation required for certain crops to reach maturity. These shifts are also relevant to water managers, who must adapt reservoir and irrigation plans to accommodate unexpected changes in rainfall timing and intensity. Infrastructure such as stormwater systems and roads may also require reassessment, particularly if high rainfall variability persists in future years.

Beyond agriculture and water systems, these changes affect local socio-economic planning. Populations in cities like Kano depend heavily on seasonal patterns for housing ventilation, market activities, and energy demand. Sudden shifts in climate behavior introduce uncertainty that can disrupt food supply chains, pricing systems, and household energy use. Studies from other tropical regions have shown that change points in rainfall patterns often coincide with major impacts on food production and water supply reliability [50], [51], [52]. Therefore, identifying the timing and nature of these shifts is not merely a statistical exercise; it supports practical adaptation strategies across sectors. In general, the change-point analysis indicates that the timing and behavior of extreme heat and rainfall events in Kano have undergone notable shifts within the study period. While these shifts are not clearly directional or sustained, they serve as early warnings of potential instability in the region’s climate system. Understanding and monitoring these shifts is essential for developing flexible, climate-resilient planning strategies that can respond quickly to emerging patterns. Continued observation and multi-year analysis will be required to determine whether these changes reflect short-term variability or the onset of longer-term transitions in Kano’s climatic extremes.

**3.4 Seasonal contribution of extreme events**

Table 2 presents the seasonal contribution of extreme heat and rainfall events, expressed as both the number of extreme days and their percentage of total events between 2015 and 2022. The table shows that extreme heat events were overwhelmingly concentrated in the spring, accounting for 98.28% of all extreme heat days. This dominance reflects the intense heat buildup that typically occurs just before the onset of the rainy season in Kano. During this period, clear skies, dry air, and intense solar radiation combine to push daily maximum temperatures above the extreme threshold. Although a few extreme heat events (1.72%) occurred in early summer, no such events were observed during autumn or winter, underscoring the seasonality of high-temperature risks in the region. On the other hand, extreme rainfall events were primarily associated with the summer season, accounting for 78.01% of all extreme rainfall days. Autumn contributed an additional 17.02%, representing residual rainfall activity following the main rainy season. Spring and winter contributed little to no precipitation, confirming that high-intensity rainfall is highly seasonal in this semi-arid region. The unequal seasonal contributions of these extremes have important implications for local planning. For instance, spring’s high heat increases irrigation demand. It increases the risk of heat-related crop damage, whereas summer’s concentration of extreme rainfall underscores the importance of adequate water storage and flood control systems.

**Table 2:** Seasonal contribution to extreme heat and rainfall events.

Season	Extreme heat (days)	Extreme rain (days)	Heat (%)	Rain (%)
Autumn	0	24	0	17.02
Spring	171	7	98.28	4.96
Summer	3	110	1.72	78.01
Winter	0	0	0	0

### 3.5 Interpretation and comparison with literature

Nigeria was selected as the case study because it lies within a climate transition zone where small changes in temperature and rainfall can produce large impacts on water availability and food production. Northern Nigeria, including Kano, is particularly sensitive due to its semi-arid climate, strong rainfall seasonality, and heavy reliance on rain-fed agriculture. The region also faces rapid population growth and increasing pressure on water resources. These factors make Kano a suitable location for examining recent climate extremes and their implications for resource management.

The results of this study confirm that extreme heat events in Kano are highly seasonal, with nearly all events occurring in spring. Similarly, extreme rainfall events are confined mainly to summer, aligning with the region's known seasonal climate structure. These findings are consistent with other research conducted in West Africa and the Sahel, where temperature extremes tend to peak just before the onset of the rainy season, while rainfall extremes follow the timing of the West African [53], [54], [55]. The absence of statistically significant trends in either extreme heat or rainfall events over the study period may seem surprising when compared to other studies that have observed clear warming trends or changing rainfall behavior. However, this outcome can be explained by the relatively short duration of the dataset used in this study, covering only eight years. In such a timeframe, natural climate variability can mask long-term shifts, especially in transitional zones like Kano where interannual variability is high. In addition, the data show year-to-year fluctuations in extremes, and change-point analysis suggests that abrupt shifts occurred in 2016 and 2020 for heat and rainfall, respectively. These shifts reflect underlying variability that may be driven by regional atmospheric dynamics or by global climate signals, such as ENSO or sea-surface temperature anomalies.

## 4. Recommendations and future research

While this study provides insight into recent temperature and rainfall extremes, the eight-year record limits the detection of long-term climate trends. Longer observational records would improve understanding of whether the identified change points reflect persistent shifts or short-term variability. Extended datasets would also help assess whether the timing of extreme events is changing consistently. This is especially important in semi-arid regions, where modest climate shifts can affect crop yields and water supply reliability. The results of this study can support improved water harvesting and agricultural planning. Knowledge of the seasonal concentration of extreme rainfall can inform the design and timing of rainwater-harvesting systems, small reservoirs, and surface storage structures. Understanding the dominance of extreme heat in spring can help adjust planting dates and irrigation schedules to reduce heat stress on crops. These insights are useful for improving the efficiency of water use during critical growing periods.

Future research should integrate climate extremes with crop growth and hydrological models. This would allow direct assessment of how extreme heat and rainfall influence crop productivity, groundwater recharge, and surface runoff. Further studies may also examine links between local climate extremes and large-scale climate drivers such as ENSO or land-use change. Strengthening climate monitoring and information dissemination will help farmers, water managers, and planners respond more effectively to climate variability. Such efforts can support more resilient water harvesting strategies and sustainable agricultural production in Kano and similar semi-arid regions.

## 5. Conclusion

Analysis of daily maximum temperature and rainfall extremes in Kano reveals strong seasonal control over extreme events. Extreme heat events were concentrated almost entirely in spring, while extreme rainfall events occurred mainly during summer. These patterns reflect the dominant regional climate regime and the timing of the West African monsoon. No statistically significant long-term trends were detected in the frequency of extreme heat or rainfall events during the study period. Interannual variability was evident for both variables. Change-point analysis identified a shift in

extreme heat occurrence after 2016 and a shift in extreme rainfall frequency around 2020. These shifts indicate short-term variability rather than a persistent directional change. The results highlight the importance of seasonality and timing in understanding climate extremes in semi-arid regions. Variability in extreme events can occur even in the absence of clear trends. Such behavior underscores the need for localized analyses when interpreting recent climate conditions in data-limited regions like northern Nigeria.

Abbreviation

**SSP** Shared Socioeconomic Pathways

**MK** Mann-Kendall

**ITA** Innovative Trend Analysis

**PCI** Precipitation Concentration Index

**RCP** Representative Concentration Pathway

**SST** Sea Surface Temperature

**WCAR** West China Autumn Rainfall

**ENSO** El Niño–Southern Oscillation

**PDO** Pacific Decadal Oscillation

**EAJ** East Asian jet

**Data availability:** The data is available upon request from the author.

**Declaration:** The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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